

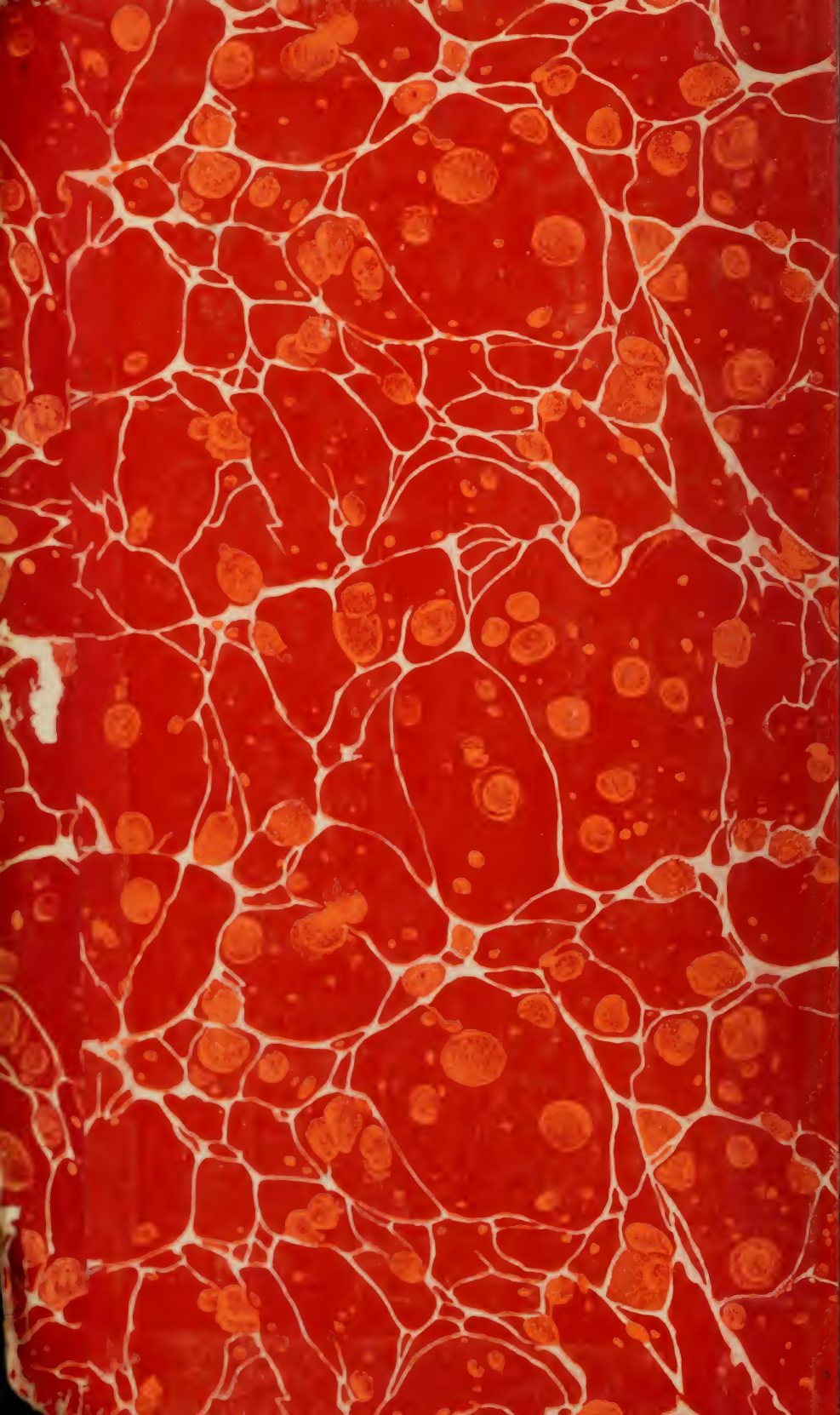
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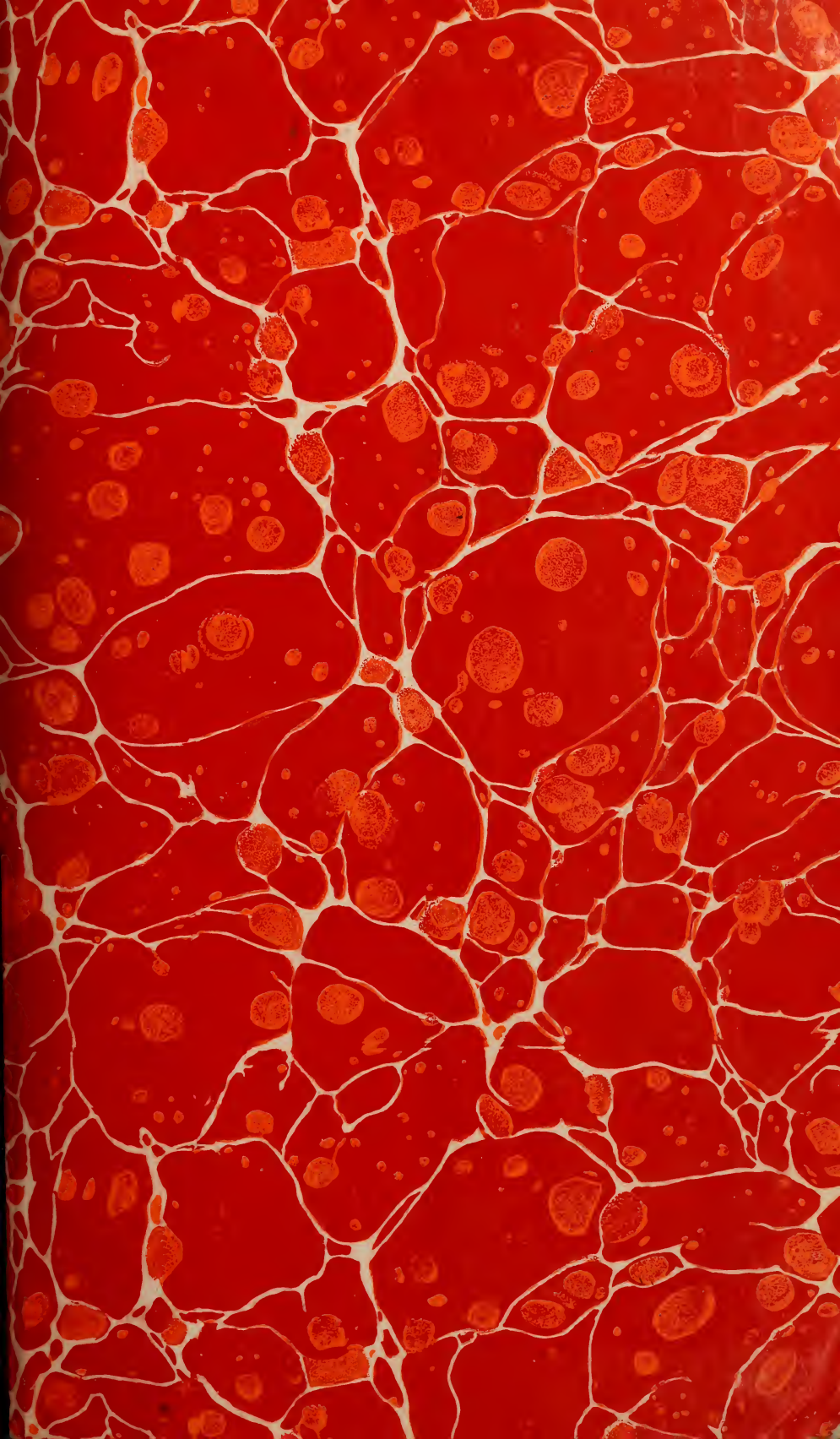
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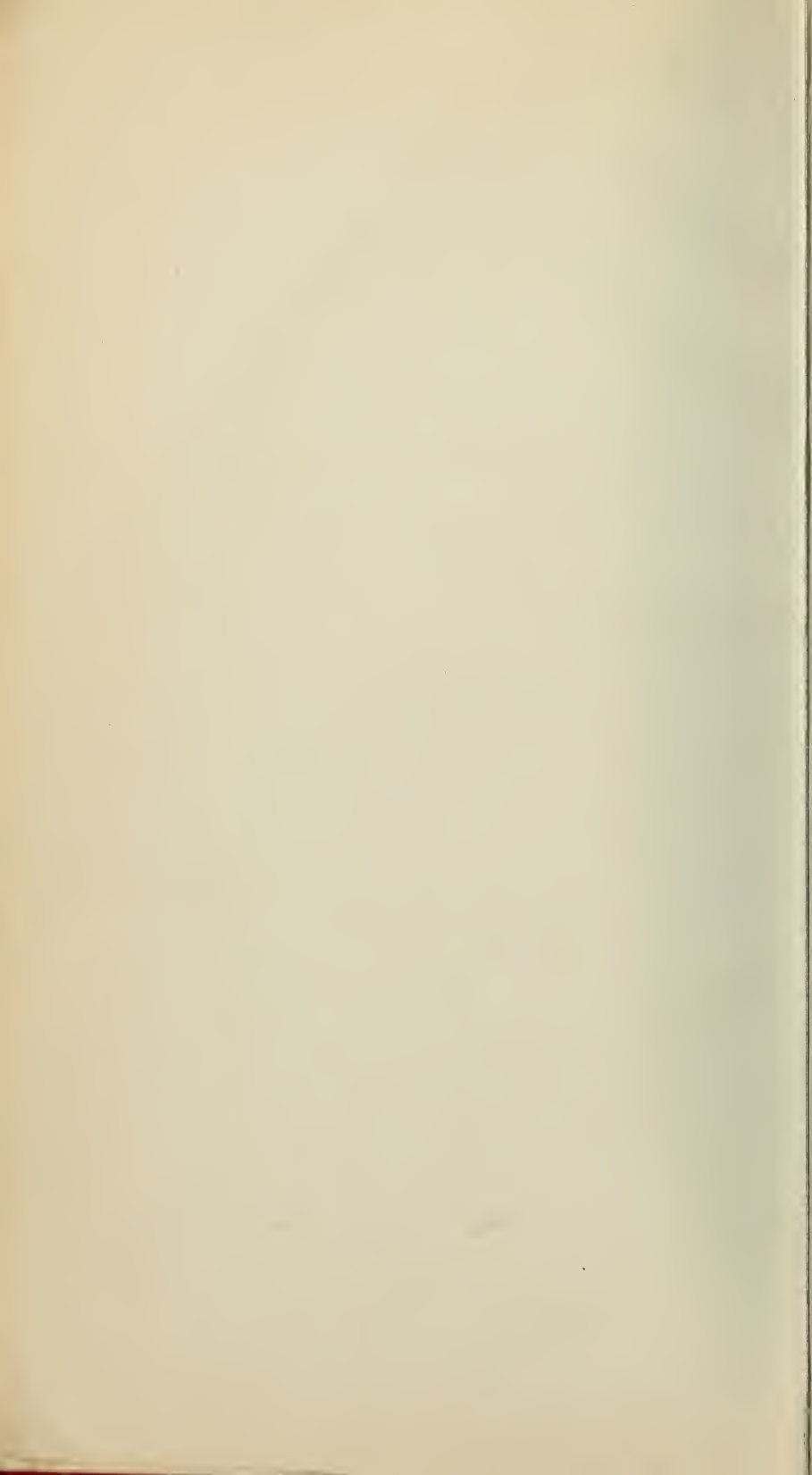
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THE WAIDNER-BURGESS STANDARD OF LIGHT

By H. T. Wensel, Wm. F. Roeser, L. E. Barbrow, and F. R. Caldwell

ABSTRACT

A source of light sufficiently reproducible to serve as a fundamental photometric reference standard has been obtained by carrying out the original suggestion of Waidner and Burgess to immerse a hollow inclosure in a bath of molten platinum and to make observations during the period of freezing.

The platinum, of exceptionally high purity, was contained in thorium oxide crucibles and was heated by means of a high-frequency induction furnace. The brightness of the source, reproducible to 0.1 per cent, was 58.84 international candles per square centimeter.

The platinum used was not appreciably contaminated by being melted and frozen over 100 times in crucibles of fused thorium oxide. Various tests indicated that the platinum was at all times purer than 99.997 per cent.

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I. EXISTING UNITS AND STANDARDS

Since visible light, by its very definition, involves physiological and psychological reactions, it is not possible to derive a unit of light from the units of a purely physical system. To measure light, an arbitrary unit must be established, in addition to the arbitrary units upon which a physical system may be based. For example, a unit of luminous intensity might be defined as the light corresponding to radiation of a specified spectral distribution or quality and of a specified energy flux per unit solid angle. Such a unit would have the appearance of being derived from those of the physical system, but light is of such a nature that the derivation has no special significance, the practical value of the unit depending solely upon its reproducibility.

At present there are no means available for determining radiant energy quantitatively with an accuracy approaching that desired in modern photometry. Consequently, instead of describing the radiant energy, we are obliged to fall back upon a specification of the source which produces it. Any light source, therefore, which is reproducible from specifications, and which consequently emits visible radiation

the quantity and quality of which are fixed by such specifications, may be used as a fundamental reference standard. As another consequence of the nature of light, any such standard defines a unit of only limited applicability, in that it can be used to evaluate light of any other spectral distribution only by introducing an additional specification regarding the relative weights to be assigned to radiations of various wave lengths. Fortunately, such a specification, in the form of a table of visibility factors, has already been adopted by the International Commission on Illumination.¹

Beginning with the sperm candle defined in the British metropolitan gas act of 1860, a large number of standards, more or less reproducible from specifications, have been proposed and some of them adopted. The most widely used have been the Pentane lamp, described by H. E. Vernon Harcourt² in 1877 and the Hefner lamp devised by F. von Hefner Alteneck³ in 1884. These flame standards are not, however, satisfactory, first because the lamps themselves are not accurately reproducible, and second because their light output is dependent to a great extent on atmospheric conditions which can not be controlled with sufficient accuracy.

A standard entirely different in principle was proposed by Violle.⁴ This standard is a luminous surface of platinum at its freezing point, the light from 1 square centimeter of which is called the Violle. It seemed to give promise of ending the search for a satisfactory reproducible standard and was adopted by the International Electrical Congress in 1889, the one-twentieth part of the Violle being given the name "Bougie décimale." However, this standard proved to be even less reproducible than the flame standards. The presence of a slight amount of foreign material on the surface greatly affects the amount of light emitted. Moreover, it was found by Burgess⁵ that the emission from incandescent platinum has a well-marked discontinuity at the freezing point, a decrease of some 15 per cent for red light occurring upon freezing without change in temperature. Whatever the cause, published values⁶ for the light emitted by the Violle standard differ by over 20 per cent from the originally assigned value.

No fundamental reference standard reproducible accurately enough for the purposes of modern photometry has been available and no one primary standard has been universally accepted. In 1909 the then existing units of candlepower of Great Britain, France, and the United States were brought into agreement⁷ and the resultant unit was termed the international candle. Germany and the other countries which had previously adopted the Hefner standard continued to use the unit derived therefrom, but its value was accepted as being 0.9 of the international candle. The international unit has since then been maintained by means of carbon-filament lamps deposited in the various national laboratories. While these lamps have for the present the status of primary standards, it was recognized at the time that their adoption was only a temporary expedient and that they would in time be superseded by some reproducible standard.

¹ Recueil des Travaux, I. C. I. 6th session, p. 67, Geneva; 1924. See also B. S. Sci. Papers, 19, p. 131; 1923-24. Trans. Illum. Eng. Soc., 19, p. 176; 1924; and 20, p. 629; 1925.

² B. A. Report, p. 845; 1898.

³ E. T. Z., 5, p. 20; 1884.

⁴ C. R., 88, p. 171; 1879; Ann. de Chim. et Phys., 3, p. 373; 1884.

⁵ B. S. Bull., 2, p. 591; 1914.

⁶ Zs. f. Instrk., 11, p. 161; 1891; 14, p. 267; 1894.

⁷ B. S. Circular No. 15; 1909.

II. BLACK-BODY RADIATION STANDARDS

In 1908 Waidner and Burgess⁸ suggested as a standard of light a black body immersed in a bath of freezing platinum. This suggestion retained the one desirable feature possessed by the Violle standard, namely, a reproducible temperature at which to operate the radiator, and at the same time avoided the variations arising from the character of the radiating surface. This suggestion received much favorable comment, but it was many years before any serious attempt was made to realize the standard in practice.

In 1924, Ives⁹ set up a light source somewhat along the lines of the Waidner-Burgess suggestion. He fashioned cylinders of platinum foil, the ends of which were clamped in heavy terminals. An electric current passing through the platinum was regulated so as to bring the temperature up slowly to the point where the cylinders melted. A longitudinal slit in the platinum foil permitted the light from the interior "black body" to emerge and to be compared with other light sources. Although Ives did not realize the standard of Waidner and Burgess, he perfected a source which was reproducible to a higher degree than any previously devised. For the brightness of this source Ives obtained a value of 55.40 candles per square centimeter.

In 1926, Brodhun and Hoffmann¹⁰ set up a black-body furnace, the temperature of which was determined by the fusion of a small bit of pure platinum welded between the hot junctions of a 90 Pt-10 Rh to 60 Pt-40 Rh thermocouple. The melting of the pure platinum manifested itself in a slight halt in the emf.-time curve of the thermocouple, so that observations, made slightly before and slightly after the thermocouple indicated the melting temperature, could be corrected by means of the thermocouple readings. The result obtained by these workers was 65.24 Hefners per square centimeter, which, on the basis of the conversion factor 0.9, is equivalent to 58.72 international candles per square centimeter. Comparisons of candlepower of carbon-filament standard lamps made between the Physikalisch-Technische Reichsanstalt and the National Bureau of Standards during the last decade have been somewhat discordant, but on the whole have indicated that the ratio of the Hefner unit to the candle as maintained at the bureau is somewhat less than 0.9. Measurements made on a group of lamps in 1926 gave a ratio of 0.893. On this basis the result obtained by Brodhun and Hoffmann is equivalent to 58.26 candles per square centimeter.

Since Brodhun and Hoffmann used resistance furnaces wound with iridium and with a platinum-iridium alloy, the platinum melt sample was subject to contamination by iridium. A platinum wire which was allowed to remain in the furnace at a temperature near the melting point of platinum was found after some time to have undergone a marked change in thermoelectric properties in a direction to indicate the addition of iridium. Another source of error lies in the fact that it is practically impossible to secure temperature uniformity in a resistance-wound furnace. No estimate is given of the temperature differences existing within the furnaces used by Brodhun and Hoff-

⁸ Elec. World, 52, p. 625; 1908.

⁹ J. Frank. Inst., 197, p. 147; 1924. Also Rec. des Travaux I. C. I. Geneva, p. 77; 1924.

¹⁰ Zeits. f. Phys., 37, p. 137; 1926.

mann. They merely state that the reading of the thermocouple depended on its location in the furnace.

The contamination of the platinum specimen by iridium is perhaps of no great consequence, since each specimen is in the furnace only for the length of time required to make one run. The temperature differences within the furnace present a more serious difficulty. Brodhun and Hoffmann observed the light coming from a small auxiliary hollow inclosure within the furnace, the thermoelement and bit of platinum being behind the back wall of this small cavity. The remarkably consistent results obtained in this work do not necessarily indicate that the specimen of platinum and the inner black body were at the same temperature, since a constant difference in temperature would likewise yield consistent results. In any case the question remains whether the conditions existing in the furnaces used in this work could be reproduced in furnaces constructed in other laboratories.

Fleury¹¹ and Chappius¹² have been working with a black body, the temperature of which is defined by the ratio (N) of its radiation (at wave length 0.622μ) to that of a black body held at the gold point. The ratio is measured by means of a spectrophotometer and a sector disk. For a radiator matching in color the carbon filament standard lamps N lies between 450 and 470. The precision is estimated at better than 1.4 per cent.

Since in the source used by Ives only a comparatively narrow ring is at the melting point, much of the light emitted comes initially from colder portions of the tube. It was to be expected, therefore, that the value obtained by Brodhun and Hoffmann for a black body within a furnace would be somewhat higher than the value obtained for the brightness of the platinum cylinder source, but the large difference actually found was somewhat disturbing. This difference showed the necessity for further experimental work, and when such was undertaken at the National Bureau of Standards in July, 1928, it was decided to set up a source in exactly the manner suggested by Waidner and Burgess, namely, to immerse a black body in a bath of molten platinum and to take observations during the time the platinum is solidifying.

III. APPARATUS AND METHODS

1. THE FURNACE AND CRUCIBLE

In the present work especial attention was given to the elimination of the two possible sources of error which may have been present in the work of Brodhun and Hoffmann, contamination of the platinum by metallic vapors and lack of temperature uniformity. The use of an induction furnace to generate the heating currents in the platinum itself eliminated all the usual sources of contamination with the exception of the refractories used to hold the platinum and to provide thermal insulation.

The uniformity of temperature, which was sought by immersing the black body in molten platinum, was further promoted by the violent stirring in the metal which results from the action of the

¹¹ Ann. de Phys. et de Chimie, 5, p. 265; 1926.

¹² Proc. I. C. I. Saranac Inn, pp. 1102 and 1109; 1928.

magnetic field of the coil of the induction furnace on the currents induced in the metal. Thus when the metal is allowed to cool slowly without entirely cutting off the power supplied to the furnace, a practically uniform temperature within the metal is assured at the instant solidification begins.

The arrangement of crucible, immersed black body or sight tube, insulation, and platinum is shown in Figure 1 and a photograph of a

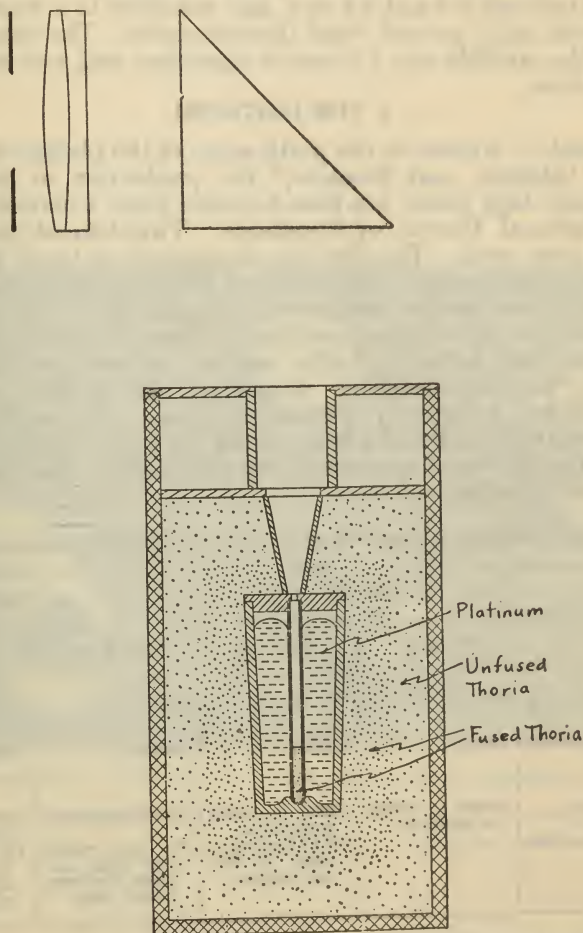


FIGURE 1.—Cross section showing the platinum crucible and insulation

cut-away view of the assembly in Figure 2. The crucible and sight tube, as described elsewhere in this journal,¹³ were made of fused thorium oxide. They were surrounded by two layers of the same material, the inner layer being fused and ground and the outer unfused. The unfused material provides the greater part of the thermal insulation, but it is subject to a large shrinkage upon heating to high

¹³ B. S. J. of Research, 6, p. 1131; 1931.

temperatures. The purpose of the fused material next to the crucible is to prevent leakage of the platinum through cracks which develop in the crucible. No trouble was experienced due to cracking of the sight tubes because of the slight temperature gradient through them.

The inside dimensions of the crucibles were substantially as follows: Diameter at the top 22 mm, diameter at the bottom 17 mm, height 45 mm. The sight tube had an inside diameter of 2.5 mm, a wall thickness between 0.2 and 0.3 mm, and was filled to a depth of about 15 mm, with finely ground fused thorium oxide. The opening in the cover of the crucible was 1.5 mm in diameter, and was coaxial with the sight tube.

2. THE PLATINUM

As a result of studies on the purification of the platinum metals by Wichers, Gilchrist, and Swanger,¹⁴ the production of platinum of exceptionally high purity has been for some years a matter of routine at the National Bureau of Standards. Two lots of platinum so prepared were used. The first lot, designated as ingot No. 1, was melted and frozen some 150 times in four different crucibles of thorium oxide, and the second lot, designated as ingot No. 2, was melted and frozen about 100 times in two crucibles. These two ingots of platinum were tested, both before and after use, for temperature coefficient of resistance, for thermoelectric properties, for impurities spectrographically and for iron by chemical analysis. The results of these tests, summarized in Table 1 below, show that the purity of the platinum was not decreased appreciably by repeated melting and freezing in the thorium oxide crucibles.

TABLE 1.—Results of tests indicative of the purity of the platinum used

Criterion of purity	Ingot No. 1		Ingot No. 2	
	Before use	After use	Before use	After use
Emf. (microvolts at 1,200° C.), v. Standard platinum.	33-----	89-----	46-----	51.
Temperature coefficient of resistance $\frac{R_{100}-R_0}{100 R_0}$.	0.003918-----	0.003903-----	0.003915-----	0.003904.
Chemical analysis-----	0.99998 to 0.99999 of platinum.	0.99997 to 0.99998 of platinum.	0.99998 of platinum.	0.99997 to 0.99998 of platinum.
Spectrographic analysis-----		Spectroscopic traces of iron and calcium.	Fe, very weak; Ca, weak; Al, trace; Mg, trace; others, none.	Fe, very weak; Ca, weak; Al, trace Mg, none?; others, none.

While the thermoelectric test is, perhaps, the most sensitive that can be applied in the detection of impurities, the temperature coefficient is generally recognized as the surest guide since small amounts of any impurity will lower the temperature coefficient. The highest value of which we have record for platinum is 0.003925, which may be taken as the value for annealed platinum free from all impurities. Although there are few data available for estimating the effect of small amounts of impurities on the freezing point of platinum, the indications are that the amount of impurity present in the platinum used in this work was not great enough to change the freezing point

¹⁴ Trans. A. I. M. M. E., 76, p. 602; 1928.



FIGURE 2.—*Photograph of platinum ingot and refractory parts*

by more than 0.1° or 0.2° C., corresponding to a change in brightness of the standard of less than 0.2 per cent. Any platinum having a temperature coefficient of resistance of 0.00390 or more should serve to reproduce the standard within the limits that can be detected photometrically.

3. THE PHOTOMETRIC ARRANGEMENT

The substitution method of photometry was employed, the general arrangement of the apparatus being shown schematically in Figure 3. This is a horizontal plan view excepting that the black body furnace, F , and the 45° total reflecting prism above it are shown rotated from their true position through an angle of 90° about the dotted line. Light from the opening in the black body at F passes vertically upward, is turned through an angle of 90° by the prism and passes horizontally through the lens L and the diaphragm K . The diaphragm was chromium plated and then blackened. The lens L forms an image of the opening in the black body upon the reflecting test plate H of magnesium carbonate. N is a transmitting test plate

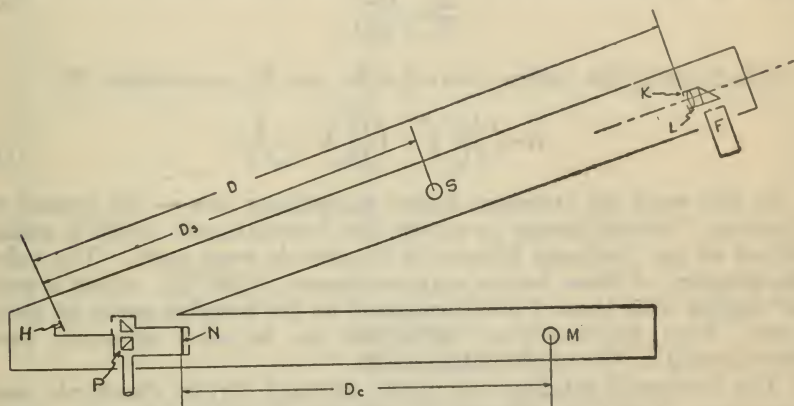


FIGURE 3.—Plan diagram of the photometer and track

illuminated by light from a comparison lamp M . The apparent brightnesses of these two test plates as seen in the Lummer-Brodhun photometer head at P are adjusted to equality by moving the comparison source.

The optical principle employed is that the illumination of an image produced by an optical system is equal to the product of the brightness of the object and the solid angle of the cone of rays illuminating the image multiplied by the transmission of the optical system.

The illumination E_B on the test plate H due to the image of the black-body opening is given by the formula,

$$E_B = \frac{BAT}{D^2} \quad (1)$$

where

B = the brightness of the black body in candles per square centimeters.

A = the area in square centimeters of the opening in diaphragm K .

T = the transmission of the lens and prism.

and

D = the distance in centimeters between the diaphragm K and the test plate H .

The illumination E_s on the test plate H due to the light incident on it from the standard lamp S is given by the formula

$$E_s = \frac{I}{D_s^2} \quad (2)$$

where

I = the candle power of the standard lamp S .

and

D_s = the distance between the standard lamp S and the test plate H .

If the distance between the comparison lamp M and the transmitting test plate N is D_c when a photometric balance is obtained with illumination E_B on the test plate H , and $D_{c'}$, when a photometric balance is obtained with illumination E_s on test plate H , then

$$\frac{E_B}{E_s} = \frac{D_{c'}^2}{D_c^2} \quad (3)$$

Substituting the values above for E_B and E_s in equation (3)

$$B = \left(\frac{D_{c'}}{D_c} \right)^2 \cdot \left(\frac{D}{D_s} \right)^2 \cdot \frac{I}{AT} \quad (4)$$

In this work six standard lamps comprising one of the groups of "primary" carbon lamps by which the international candle is maintained at the National Bureau of Standards were used. The color temperature of these lamps is approximately 2,080°K., which is only 35° higher than that of the black body at the freezing point of platinum. Thus, practically no difficulties due to color difference were encountered in the photometric work.

The horizontal candlepower of the primary carbon standards used was about 17 and the distance D_s between the standard lamps S and test plate H was about 125 cm, resulting in an illumination on the test plate of approximately 11 m candles. By suitably choosing the distance D and the size of the opening in the diaphragm K , approximately the same illumination was obtained when light from the black body during the freezing of the platinum was incident on the test plate. Thus, all photometric measurements that are used to calculate the black body brightness were made with the same photometer field brightness. Also, the distances D_c and $D_{c'}$ were nearly equal, so that only their difference need be known accurately. The photometric settings from which the ratio $\frac{D_{c'}}{D_c}$ was determined were automatically recorded on a drum chart, thus producing freezing and cooling curves such as the one shown in Figure 4.

4. METHOD OF MAKING OBSERVATIONS

As explained before, the metal in the liquid state undergoes a violent stirring action so that the entire mass cools to the freezing point before any part of it begins to solidify. For this reason only the observations taken during freezing were used, although the melts were

usually observed. The melts did not differ materially from the freezes, but were usually not as sharply defined at beginning and end. As shown in Figure 4 undercooling before freezing almost invariably occurred.

The procedure in making a run was as follows: The platinum was heated, and all necessary adjustments made to center the image of the black-body opening upon the test plate. To measure the distances from the test plate to the standard lamps and to the diaphragm a steel bar was next clamped in position along the optical axis of the lens. The bar had three calibrated reference marks, one near each end and one at the location of the socket for the standard lamp *S*. It was over 3 m in length, being some 12 to 15 cm shorter than the distance between the test plate and diaphragm. The bar was adjusted until

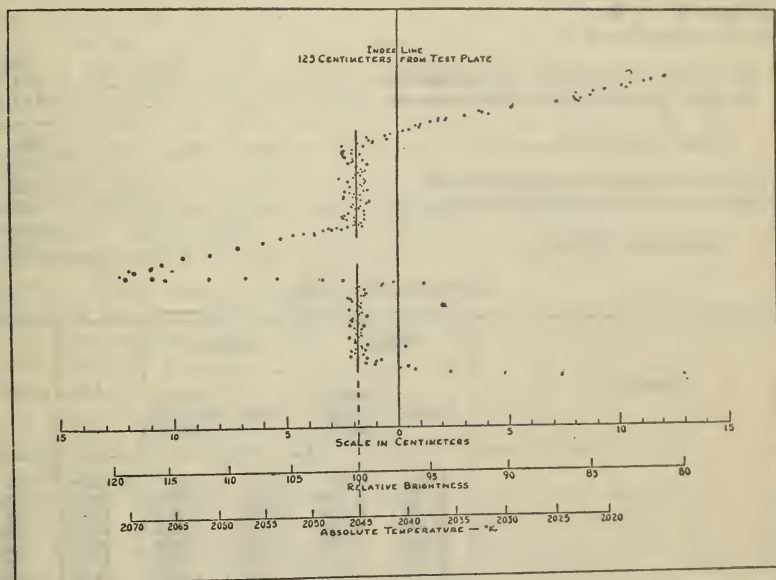


FIGURE 4.—Automatic record of a typical melt and freeze

the middle scratch coincided with the center of the lamp socket at *S* and the distances from the diaphragm *K* to one end scratch and from the test plate *H* to the other end scratch were measured with a short steel scale to within 0.2 mm.

Throughout each run the carbon comparison lamp was maintained at a constant voltage such that its color temperature was approximately midway between that of the black-body standard and that of the standard carbon lamps. The observer made photometric measurements first on three standard lamps, then on three successive freezes of the platinum standard, and finally on three additional standard lamps. Electrical measurements on both the standard and the comparison lamps were made by means of a 5-dial Dieselhorst potentiometer. Following these photometric measurements, the steel bar was again clamped in position on the optical axis and the distance measurements repeated.

The photometric settings made during a run were usually all recorded on a single drum chart. The distances between the average

settings of the comparison lamp for the black-body standard and for the standard lamps were measured by a steel scale to an accuracy of about 0.2 mm.

A sample data sheet is given below. The symbols used have the following meanings:

D , the distance between the diaphragm and the test plate.

D_s , the distance between the center of the standard lamp socket and the test plate.

D_c , the distance between the comparison lamp and the transmitting test plate when a photometric balance is obtained with illumination from the black body in freezing platinum (obtained from drum charts).

D_c' , the distance between the comparison lamp and the transmitting test plate when a photometric balance is obtained with illumination from the standard lamp (obtained from drum charts).

Date: October 10, 1929.

Drum charts: 46 and 47.

Observer: W. F. R.

Distance measurements:

	<i>cm</i>
D , before photometric measurements.....	341. 57
D , after photometric measurements.....	341. 60
Mean value of D	341. 59
D_s , before photometric measurements.....	125. 74
D_s , after photometric measurements.....	125. 77
Mean value of D_s	125. 76

Standard lamp data

Lamp No.	Voltage		Current		I	D_c'
	Rated	During measurements	Rated	During measurements		
	<i>Volts</i>	<i>Volts</i>	<i>Amps.</i>	<i>Amps.</i>	<i>Candles</i>	<i>cm</i>
44.....	48. 960	48. 960	1. 3314	1. 3316	17. 74	126. 35
45.....	48. 960	48. 960	1. 3291	1. 3292	17. 49	126. 69
46.....	49. 460	49. 460	1. 3203	1. 3218	17. 58	126. 55
49.....	49. 460	49. 460	1. 3292	1. 3292	17. 76	126. 20
50.....	49. 460	49. 460	1. 3269	1. 3269	17. 64	126. 20
64.....	50. 459	50. 459	1. 3320	1. 3322	18. 13	125. 16
Mean.....					17. 723	126. 19

Data on platinum freezes

Freeze No.	D_c
	<i>cm</i>
1.....	126. 69
2.....	126. 99
3.....	126. 88
Mean.....	126. 85

A , area of opening in diaphragm..... cm^2 .. 2. 8598

T , transmission of lens and prism.....per cent.. 76. 93

The brightness of the black body immersed in freezing platinum, computed from the equation (see equation (4), p. 1110)

$$B = \left(\frac{D_c'}{D_c} \right)^2 \left(\frac{D}{D_s} \right)^2 \frac{I}{AT}$$

is $B = 58.82 \text{ candles/cm}^2$.

The diameter of the opening in the diaphragm *K* was measured both with a microscope comparator by the length measurements section of the National Bureau of Standards and with gages by the gage section. The opening was found to be very slightly out of round, and this fact was taken into account in calculating the area.

The measurement of the combined transmission of the lens and prism, which enters in the result to the first order, and which proved to be somewhat of a problem, was made by two independent methods. In the first, termed the box method, a rectangular light box was constructed, the front of which contained a circular opening through which the rear wall could be viewed. The inside walls were coated with the fumes from burning magnesium ribbon, and several incandescent lamps were placed inside the box and screened so as to illuminate the rear wall as uniformly as possible. The voltage of the lamps was adjusted so that the color temperature of the light from the box and that of the comparison lamp were made equal to that of the black body. Observations were then made by matching the comparison test plate with the rear wall of the box, first directly and next with the prism and lens interposed between the light box and the photometer head. The identical area of the rear wall of the box could not be viewed in the two observations so that irregularities in the brightness of this wall affected the consistency of the results obtained. By making a large number of determinations the effect of nonuniformity of the brightness of the rear wall should be eliminated. However, it was deemed advisable to check the results thus obtained by an entirely different method, using an optical pyrometer.

In the optical-pyrometer method, the black-body standard itself was used as a source of uniform brightness and proper spectral distribution. An optical pyrometer was sighted through the lens and prism into the black body during freezing of the platinum and the current through the pyrometer lamp necessary to secure a match was determined. The red screen was, of course, removed from the pyrometer for this purpose. Next a sector disk having the same transmission as that which the box method had yielded for the lens and prism was substituted for these optical parts, and the current through the pyrometer lamp necessary to secure a match during a freeze of the platinum was again determined. Two other sectors were also used, one having a slightly greater and one a slightly smaller transmission than the first in order to determine the relation between the current through the lamp and the transmission in this region. As it happened, the last two sectors were scarcely needed because the current through the lamp in the two cases, when the first sector and when the lens and prism were used, differed by only 1 part in 10,000, corresponding to a difference of 1 part in 2,000 in the transmission.

Each of three observers made 4 sets of observations, representing in all 18 freezes using the first sector and 18 freezes using the lens and prism. The values obtained are listed in Table 2.

TABLE 2.—Data on transmission of lens and prism

Observer	Box method	Optical-pyrometer method
	<i>Per cent</i>	<i>Per cent</i>
H. T. W.	76.93 (Average of 12 sets).....	77.03 (Average of 4 sets).
W. F. R.	76.93.....do.....	76.93 Do.
F. R. C.	76.89.....do.....	76.85 Do.
E. G. A.	76.97 (Average of 6 sets).....
Mean.....	76.92	76.94

IV. RESULTS

During the first few freezes taken on ingot No. 1, a water-cooled diaphragm was used in contact with the prism. The cooling proved too effective, the prism being cooled sufficiently below room temperature to collect a slight film of moisture from the atmosphere. While these results did not differ appreciably from those obtained later, it was decided to discard all results from runs at the conclusion of which any film could be detected. With air cooling instead of water cooling, no further trouble from films was experienced and no results obtained after the change to air cooling have been discarded.

The photometric settings were made by four observers. Observers (H. T. W. and E. G. A.) had considerable previous experience in photometry, and observers (H. T. W., W. F. R., and F. R. C.) had considerable experience in precision optical pyrometry. The results of individual runs obtained are listed in Table 3, each run being the average of observations on three freezes and six primary standard lamps.

TABLE 3.—Data on black-body brightness

Ingot No. 1				Ingot No. 2			
H. T. W.	W. F. R.	F. R. C.	E. G. A.	H. T. W.	W. F. R.	F. R. C.	E. G. A.
<i>c/cm²</i>	<i>c/cm²</i>	<i>c/cm²</i>	<i>c/cm²</i>	<i>c/cm²</i>	<i>c/cm²</i>	<i>c/cm²</i>	<i>c/cm²</i>
58.69	58.48	58.92	58.46	58.61	58.81	59.13	58.53
58.87	58.54	58.56	59.10	58.88	58.86	58.97	58.95
59.15	58.78	59.23	58.67	58.65	58.59	58.46	58.73
59.09	58.82	59.15	59.07	59.14	59.01	59.09	59.02
¹ 58.95	58.66	58.96	58.83	58.82	58.82	58.91	58.81
Mean of ingot No. 1, 58.85 candles per cm ² .				Mean of ingot No. 2, 58.84 candles per cm ² .			

¹ Mean values.

V. DISCUSSION OF ERRORS

The precision attainable in visual photometry is generally considered to be no better than 1 part in 1,000, and it would be very gratifying if one could be assured that the value for the brightness of the Waidner-Burgess standard has been determined to this order of accuracy. The agreement of the results obtained with ingot No. 1 and ingot No. 2, to 1 part in 6,000 may be looked upon as an unusual coincidence. It is believed, however, that the standard as used in this work is reproducible in any suitably equipped laboratory to within 1 part in 1,000.

The uncertainty in the value obtained for the brightness, due to errors in the measurement of the opening in the limiting diaphragm used is too small to affect the result by more than 0.03 per cent. The distance measurements were all made with sufficient accuracy to make the resultant error negligible, about 0.02 per cent. The measurement of the transmission of the lens and prism, made by two independent measurements each of which is probably good to nearly 0.1 per cent, is considered good to 0.1 per cent. The value for the candlepower of the carbon lamps used is taken to be exact, our result being expressed relative to the candlepower of this group of six lamps. The various errors may be summarized as shown in Table 5.

TABLE 5.—Summary of possible errors due to various causes

	Per cent
Area of diaphragm.....	± 0.03
Distance measurements.....	$\pm .02$
Transmission of lens and prism.....	$\pm .1$
Photometric matching.....	$\pm .1$
Lack of black-body conditions and temperature drop in wall of sight tube.....	$-.2$
Sum.....	$+0.25$ to -0.45

The errors listed in Table 5 are all independent of each other and are not likely to be all of the same sign. The numerical value for the brightness in terms of the group of six lamps used in the measurements is, therefore, probably not high by more than 0.15 per cent nor low by more than 0.35 per cent.

VI. COMPARISON OF RESULTS WITH THOSE OF OTHER OBSERVERS

The values for the brightness of a black body at the platinum point obtained by Ives, by Brodhun and Hoffmann, and in the present work are given below in terms of the international candle as maintained at the National Bureau of Standards.

	c/cm ²
B_1 (Ives).....	55.40 ± 0.11
B_2 (B. & H.).....	$58.26 \pm .15$
B_3 (W., R., B. & C.).....	$58.84 + .20$ or -0.09

It is obvious that the differences in the values given above can not be due to errors in the photometric comparisons, and are likewise somewhat too large to be entirely accounted for by differences in photometric units. It would seem more logical to conclude that the sources actually differed in intrinsic brightness in the manner indicated by the measurements. It so happens that positive evidence on this point is available.

The freezing point of platinum has been determined, as described elsewhere in this journal¹⁵ by making observations with an optical pyrometer on the same black bodies for which the brightness was determined in this investigation as having the value B_3 above. The temperature obtained was $1,773.5^\circ \text{C. Int.}$ Likewise the melting point of platinum was determined by Hoffmann¹⁶ using the experimental arrangement with which the value of brightness cited as B_2 was found. The value obtained, $1,771^\circ \text{C.}$, on the basis of $C_2 = 1.430 \text{ cm deg.}$,

¹⁵ B. S. Journ. of Research, 6, p. —; 1931.¹⁶ Zeits. f. Phys., 27, p. 285, 1924.

becomes $1,769.5^{\circ}\text{C}$. when reduced to the International Temperature Scale.

Ives made no temperature measurements, but shortly after the publication of this work measurements¹⁷ were made at the National Bureau of Standards with an optical pyrometer on the radiation from small holes in platinum tubes 1 mm in diameter and having walls 0.1 mm thick. The temperature readings at the instant of melting ranged from $1,760^{\circ}$ to $1,766^{\circ}\text{C}$. More recently Ribaud and Mohr¹⁸ have made similar measurements and report a value of $1,762^{\circ}\text{C}$.

The correlation of the temperature measurements made on tubes with the value found by Ives on tubes of radically different dimensions may be open to question. However, these measurements are the only available ones made under even approximately similar conditions. Nevertheless, there can be no doubt that the radiation from such tubes at the time of failure is equivalent to that from a black body at a temperature considerably below the platinum point.

The conditions in the work of Brodhun and Hoffmann were such that the temperature of the black body used may have been either above or below the temperature of the melting platinum. The evidence, both in the case of the brightness measurements and in the case of the temperature measurements, is that the black body used by Brodhun and Hoffmann emitted less radiation than the immersed black body used in the present work, which in turn could not possibly be at a temperature above that of the freezing platinum in which it was immersed.

On the basis that the equivalent temperature and brightness of the three sources used corresponded closely to the observed values, we may calculate the value that each would have obtained with a source at $1,773.5^{\circ}\text{C}$.

Source used	Temperature of source (observed)	Brightness of source (observed)	Brightness calculated for a temperature of $1,773.5^{\circ}\text{C}$.
	$^{\circ}\text{C}$.	c/cm^2	c/cm^2
Platinum tubes.....	$1,762.5 \pm 2$	55.40 ± 0.11	59.10 ± 0.66
Resistance-wound furnace.....	$1,769.5 \pm 2$	58.26 ± 0.15	59.64 ± 0.66
Black body immersed in platinum.....	$1,773.5 \pm 1$	58.84 ± 0.09	58.84 ± 0.09

Since a change of 1°C . in the temperature of a black body at the platinum point corresponds to a change of almost 0.6 per cent in brightness, the accuracy of the temperature measurements described is not as great correspondingly as the accuracy of the photometric measurements.

VII. BLACK-BODY STANDARDS OF HIGHER COLOR TEMPERATURES

The choice of the type of lamp for use in maintaining the value of the international candle was made before the advent of incandescent lamps of higher luminous efficiencies than those with carbon filaments. To-day the carbon lamp has passed almost completely from general

¹⁷ Unpublished work by C. O. Fairchild and H. T. Wensel; September-October, 1924.

¹⁸ C. R., 192, p. 37; 1931.

use. The question naturally arises whether a black body at the color temperature of tungsten lamps, either vacuum or gas-filled, would be a more logical standard than the platinum black body to replace the present carbon lamps as the photometric standard.

In practice, the several national laboratories maintain as working standards vacuum tungsten and gas-filled tungsten lamps, which have been calibrated in terms of the primary carbon standards by various methods. Unfortunately, the national laboratories are not in agreement on the results obtained in such calibrations, so that although they agree approximately on the unit of light as maintained by carbon standards, they do not agree on the unit as represented by derived tungsten standards. Intercomparisons indicate that the discrepancies may amount to as much as 5 per cent. Such a condition may be remedied in one of two ways. The several laboratories may agree on a procedure which will give consistent results in comparing lamps differing in color temperature or a black body at a higher color temperature may be arbitrarily set up as a standard and the unit so defined maintained by tungsten lamps. The objections against defining a new unit are the same as those against any dual standard. Moreover, since the tungsten-filament incandescent lamps in use to-day range in color temperature from about $2,400^{\circ}$ to $3,300^{\circ}$ K., no one standard will serve for all such lamps until a solution is found for the problem of comparing two lamps differing in color temperature by hundreds of degrees. A cooperative investigation is now being carried on among the national laboratories in which it is hoped the spectral transmission values of several blue filters will be agreed upon. With the use of these filters, the step from one color temperature to another can be made without the difficulties inherent in heterochromatic photometry. The solution of this problem will make the position in the color-temperature scale of the source chosen as the primary standard a matter of secondary importance.

VIII. SUMMARY

The proposal of Waidner and Burgess for a reproducible standard of light has been experimentally realized. The light emitted by a hollow inclosure of fused thorium oxide immersed in freezing platinum has been found to be reproducible within the limits that can be detected by visual photometry. The brightness of this source was determined as 58.84 ± 0.09 candles per square centimeter.

The brightness of a black body at the platinum point probably lies between 58.75 and 59.04 candles per square centimeter.

IX. ACKNOWLEDGMENTS

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